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Difference in Grain Yield and Quality among Tillers in Rice Genotypes Differing in Tillering Capacity

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Abstract: A japonica variety and its iso-allelic mutant with high tillering ability were used to investigate the differences in grain yield and quality among different tillers. There was a distinct difference in panicle weight among tillers during grain filling for both genotypes, with Xiushui 11 having a greater increase rate in panicle weight, and being earlier in reaching the maximum panicle weight than the mutant. There was a great significant difference between the two genotypes in grain yield and its components, with Xiushui 11 having higher grain yield, more grains per panicle, higher filled grain percentage and grain weight than the mutant for each type of tiller. Moreover, a significant difference was found in grain yield and yield components among different tillers for both genotypes, with grain number per panicle showing the greatest variation over tillers among all yield components. Compared with Xiushui 11, the mutant had higher brown rice rate and greater ratio of length to width of brown rice, and lower chalky rice rate, amylose content, and protein content of rice. Furthermore, there was a significant difference in grain quality among tillers within a plant for both genotypes, with later initiated tillers being lower in chalky rice rate, amylose and protein contents than early initiated ones. The variation of most quality parameters among tillers within a plant was markedly larger for the mutant than for Xiushui 11.
Key words: tiller; grain yield; rice quality; variation

A rice plant, in general, consists of main shoot and tillers, which initiate at different times and differ in growth and development patterns, depending on the time of their initiation [1]. Tillers contribute a large portion of grain yield, and the extent of the contribution varies with planting density and variety [2]. Commonly, tillers can be divided into different types according to the type of culm from which tiller is initiated, that is, a primary tiller (PT) initiated from a main culm (MC), a secondary tiller (ST) from a primary tiller, a tertiary tiller (TT) from a secondary tiller, a quaternary tiller (QT) from a tertiary tiller, and so on [2]. A synchronous relationship exists in the time of appearance and growth between a given tiller and leaf [3]. Meanwhile, a marked difference could be found in the time of leaf and panicle emergence, and grain development among tillers within a plant [4-5]. Thus, grain yield and its components vary greatly with tiller type, and early initiated tillers produce more grains than late initiated ones [2, 6]. However, little has been known about the difference in grain quality among tillers within a plant.

The high tillering capacity is considered as a desirable trait in rice production, since number of tillers per plant is closely related to number of panicles per plant [7]. To some extent, yield potential of a rice variety may be characterized by tillering capacity [1]. On the other hand, it was reported that the plants with more tillers showed a greater inconsistency in mobilizing assimilates and nutrients among tillers [7]. As a result, variation in grain development and yield among tillers is variable over the varieties differing in tillering ability. Meanwhile, variation in grain yield and quality among tillers has been considered as a major factor affecting yield potential and quality for a given rice variety. Although there were some investigations about the relationship between tillering ability and population yield [8-9], little was known about the effect of tillering ability on variation extent in grain yield and its components among tillers. Moreover, grain quality could be also affected by tillering ability due to different grain development characteristics. However, the effect of tillering ability on grain quality still remains unclear.

In the present study, a japonica variety and its mutant with high tillering ability were used to

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investigate the differences in grain yield and rice quality among tillers within a plant.

MATERIALS AND METHODS

Plant materials and planting methods

Rice variety Xiushui 11 and its mutant with high tillering ability were seeded in late May and transplanted in late June, 2004 at the experimental farm of Zhejiang University (Huajiachi Campus). Each genotype was grown with two replications in an eight-line plot, 2 m long and 20 cm between lines, with nine hills each line and one seedling per hill. The trial was managed according to the locally recommended agronomic practices.

Ten days after transplanting, 20 uniform hills (plants) per plot were selected and tagged for tillering observation. Newly initiated tillers of each plant were checked and tagged every two days. At maturity, all of the tagged plants were harvested and separated into different panicles according to their tillering types, and oven-dried at 80℃ for 72 h.

Measurements

Panicle length, number of grains per panicle, and grain weight were determined for each sample, and the filled grain percentage and grain density in panicle were calculated. All grain samples of different tillers were de-husked with a rubber husker (Model JNMJ3, Taizhou Foodstuff Machine Factory, China) to determine brown rice percentage (BRP), and de-husked rice was further milled with a miller (Model JGJ45, Qianjiang Machine Factory, China) to determine head rice percentage (HRP). Chalky rice is defined as a rice individual with opaque or white portions by observing rice profile with naked eyes, and chalky rice rate was calculated. Amylose content (AC) was determined according to Williams et al [10] and protein content (PC) was measured with Kjeldahl method.

RESULTS

Grain filling process of different tillers

As shown in Fig.1, there was a distinct difference in panicle weight among different culms during grain filling for both genotypes, with earlier initiated tillers having higher panicle weight than later initiated ones, but the differences between MC and PT for Xiushui 11 and between PT and ST for the mutant were not significant. The maximum difference in panicle weight among tillers occurred at mid grain filling stage for Xiushui 11, while the difference of the mutant increased with grain development. Furthermore, Xiushui 11 showed little increase in panicle weight of all culms at late grain filling (25 d after flowering), while the mutant showed a consistent increase during the whole grain filling period.

An obvious difference could be found in panicle weight increase rate (g/d) between the two genotypes, with Xiushui 11 being higher than the mutant for all tillers, as shown in Fig. 2. Moreover, Xiushui 11 and

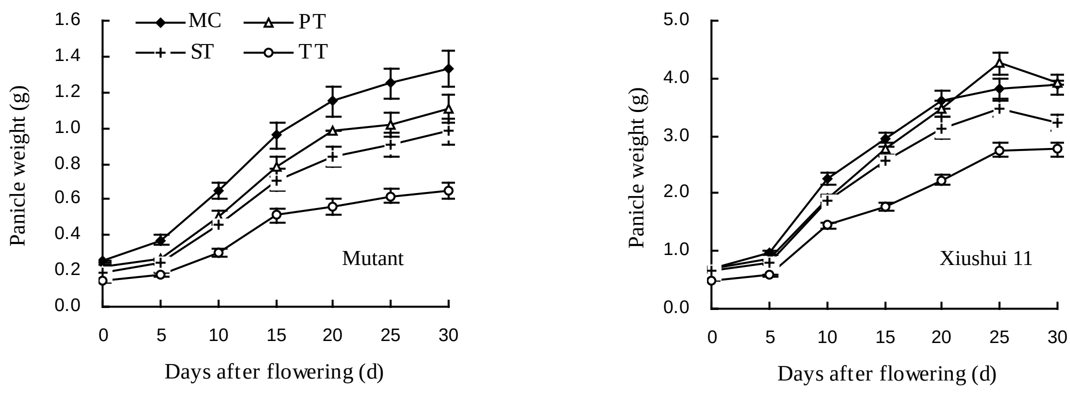

Fig. 1. Panicle dry weight of MC (main culm), PT (primary tiller), ST (secondary tiller), and TT (tertiary tiller) for Xiushui 11 and the mutant during grain filling.

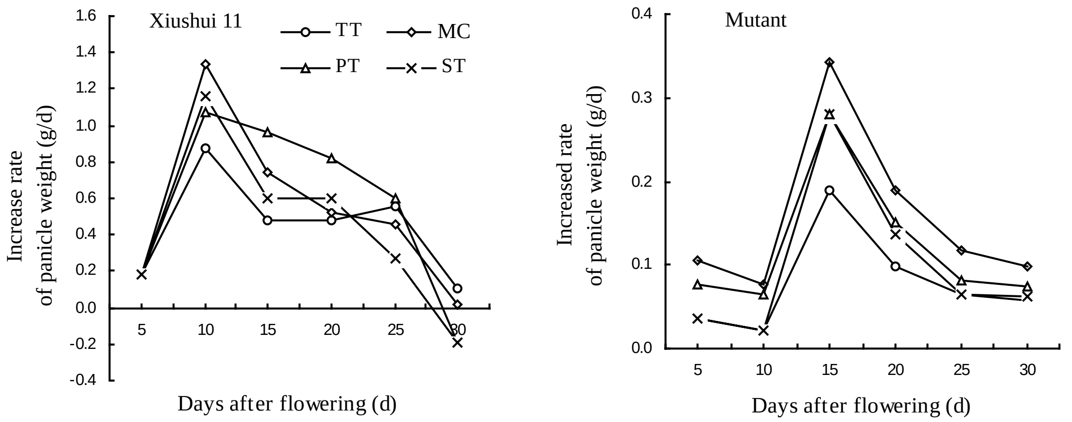

Fig. 2. Increasing rate of panicle weight of MS (main culm), PT (primary tiller), ST (secondary tiller), and TT (tertiary tiller) for Xiushui 11 and the mutant during grain filling.

the mutant reached the highest panicle weight increase rate at 10 and 15 days after flowering, respectively.

Differences in grain yield and yield components among different tillers

As shown in Table 1, there was a significant difference between the two genotypes in grain yield and its components, with Xiushui 11 having higher grain yield, number of grains per panicle, filled grain percentage, and grain weight than the mutant for all culms.

A distinct difference in grain yield among culms was found for both genotypes. For Xiushui 11, there was no significant difference between MC and PT, but both of them were significantly higher than ST and TT. For the mutant, MC had the highest grain yield per panicle, significantly higher than all other tillers. However, there was no significant difference between PT and ST. TT of both genotypes had the lowest grain yield per panicle. In addition, significant difference could be found in grain yield per panicle for the same kind of tiller between the two genotypes, with the mutant being significantly lower.

A marked difference was found in number of grains per panicle among culms for both genotypes, with the order of MC>PT>ST>TT. Compared with the mutant, Xiushui 11 had more grain number per panicle for each kind of tillers (Table 1).

Grain number per panicle is the function of panicle length and grain density. It could be seen from Table 1 that Xiushui 11 had significantly longer panicle length and higher grain density than the mutant. Among tillers, there was a significant difference in both panicle length and grain density, with earlier initiated tillers being greater than late initiated ones.

Similarly, a significant difference in filled grain percentage was found among different culms, although the difference was much smaller than other yield components, which was reflected by variation among tillers (*CV*). Both genotypes had the highest filled grain percentage in ST, followed by PT, and both of them were significantly higher than MS and TT. In comparison with the mutant, Xiushui 11 had significant higher filled grain percentage for each kind of tillers.

Xiushui 11 had significantly higher grain weight than the mutant for all kinds of tillers. The differences among tillers varied with genotypes. For Xiushui 11, PT had the highest grain weight, significantly higher than any other tillers, and there was no significant difference between ST and TT. While for the mutant, there was no significant difference in grain weight among MS, PT and ST, although all of them had significantly higher grain weight than TT.

Differences in rice quality among different tillers

There was a distinct difference in brown rice rate (BRR) between Xiushui 11 and the mutant, with the latter having higher BRR than the former. However, there was no significant difference among tillers in BRR for both genotypes (Table 2).

Table 1. Grain yield and panicle characteristics of different tillers.

Character	Genotype	Main culm (MC)		Primary tiller (PT)		Secondary tiller (ST)		Tertiary tiller (TT)		Mean		CV(%)
Panicle length (cm)	Xiushui 11	22.77	a	21.57	b	18.97	c	18.03	c	20.33		10.85
	Mutant	12.80	a**	12.55	a**	12.50	a**	10.26	b **	12.03	**	9.86
Grain density (grains/cm)	Xiushui 11	5.92	a	5.83	a	5.27	b	4.75	c	5.44		9.95
	Mutant	4.73	a**	3.74	b**	3.64	b**	3.07	b **	3.80	**	18.20
Number of grains per panicle	Xiushui 11	134.67	a	125.67	b	100.00	c	85.67	d	111.50		20.30
	Mutant	60.50	a**	47.00	b**	42.50	c**	31.50	d**	45.38	**	26.45
Filled grain percentage (%)	Xiushui 11	93.61	b	96.30	a	97.18	a	90.57	c	94.41		3.16
	Mutant	86.71	b**	84.04	b**	91.10	a**	86.07	b*	86.98	**	3.42
Grain weight (mg)	Xiushui 11	29.48	b	31.89	a	27.37	c	26.33	c	28.77		8.56
	Mutant	23.56	a**	23.08	a**	23.48	a**	21.38	b**	22.86	**	4.42
Grain yield per panicle (g)	Xiushui 11	3.72	a	3.86	a	2.66	b	2.04	c	3.07		28.28
	Mutant	1.24	a**	0.91	b**	0.91	b**	0.58	c**	0.91	**	29.51

Within a row, values followed by different letters represent significant difference at 95% probability; *,** indicate significant difference between Xiushui 11 and the mutant for a given characteristic at 95% and 99% probability levels, respectively.

Table 2. Differences in rice quality among tillers for the two genotypes.

Quality characteristic	Genotype	Main culm (MC)		Primary tiller (PT)		Secondary tiller (ST)		Tertiary tiller (TT)		Mean		CV(%)
Brown rice rate (%)	Xiushui 11	83.94	a	83.51	a	83.66	a	83.85	a	83.67		0.34
	Mutant	84.49	a*	84.03	a	84.63	a	85.18	a*	84.59	**	0.56
Brown rice length (mm)	Xiushui 11	4.88	ab	4.95	a	4.80	b	4.85	b	4.87		1.28
	Mutant	4.91	a	4.85	a*	4.75	ab	4.63	b*	4.78		2.47
Brown rice width (mm)	Xiushui 11	2.85	a	2.90	a	2.80	a	2.88	a	2.86		1.49
	Mutant	2.48	a*	2.48	a*	2.52	a*	2.39	b*	2.46	*	1.95
Ratio of length to width of brown rice	Xiushui 11	1.71	a	1.71	a	1.71	a	1.68	a	1.70		0.82
	Mutant	1.98	a*	1.96	a*	1.89	a*	1.94	a*	1.94	*	2.08
Chalky rice rate (%)	Xiushui 11	44.47	a	38.72	ab	34.25	bc	31.52	c	37.24		15.19
	Mutant	39.27	a	32.21	b	29.97	b*	25.10	c*	31.64	*	18.61
Amylose content of rice (%)	Xiushui 11	16.32	b	17.98	a	15.68	bc	14.93	c	16.23		8.00
	Mutant	16.48	a	15.61	a**	15.22	a	12.93	b*	14.58	*	9.93
Protein content of rice (%)	Xiushui 11	10.72	a	10.23	b	9.74	b	10.22	b	10.23		3.89
	Mutant	9.84	a*	9.49	b*	8.84	c*	8.49	d**	9.17	*	6.63

Within a row, values followed by different letters represent significant difference at 95% probability; *,** indicate significant difference between Xiushui 11 and the mutant for a given characteristic at 95% and 99% probability levels, respectively.

Averaged over all kinds of tillers, there was no significant difference in brown rice length between the two genotypes (Table 2). While for brown rice width, Xiushui 11 was significantly larger than the mutant, and there was a significant difference in ratio of length to width of brown rice between the two genotypes, with Xiushui 11 being smaller. The differences in brown rice length, brown rice width, and ratio of length to width of brown rice among tillers varied with genotypes. For Xiushui 11, PT had the greatest brown rice length, significantly greater than ST and TT, and for the mutant, there was no significant difference among tillers. In contrast, no significant difference was found in brown rice width among tillers for Xiushui 11, and for the mutant, TT had significantly smaller brown rice width than the other tillers. Both genotypes had no significant difference in ratio of length to width of brown rice among tillers.

As shown in Table 2, there was a distinct difference in chalky rice rate between Xiushui 11 and the mutant, with the mutant being less than Xiushui 11, when averaged over all kinds of tillers. However, there was no significant difference in chalky rice rate of both MC and PT between the two genotypes. Among tillers, the earlier initiated ones had larger chalky rice rate than later ones, irrespectively of genotypes. Moreover, chalky rice rate had the largest variation over tillers among all the quality characteristics.

There was a significant difference in amylose content of rice between the two genotypes for the mean of all tillers and every kind of tillers, except MC and ST. Moreover, the difference among tillers varied with genotypes (Table 2). For Xiushui 11, PT had the highest amylose content, significantly higher than any other tillers. Whereas for the mutant, there was no significant difference among MC, PT and ST, although they had the significantly higher amylose content than TT.

Xiushui 11 showed significantly higher protein content of rice than the mutant for all kinds of tillers. Within a plant, MC had the highest PC, irrespectively of genotypes. The difference among three later initiated tillers varied markedly with genotypes. As seen from Table 2, there was a significant difference among these tillers for the mutant, while for Xiushui11, no significant difference was found among PT, ST and TT.

DISCUSSION

Tillering ability in rice, to some extent, is closely related with panicle number and thus yield. The great effort has been done in investigating relationship between tiller number and grain yield through partially deleting tillers, light inducement and changing nutrient conditions. It has been well documented that either excessive or insufficient tillering is unfavorable for high yield [8-9]. In the present study, the mutant had more panicles, but its grain yield per panicle was markedly lower than Xiushui 11. It was also found that grain number per panicle showed the greatest variation over tillers among all yield components, indicating that more tillers bring obvious negative impact on grain number per panicle, leading to reduced panicle weight. It may be assumed that the grain number per panicle was more affected by the increased competition than other yield components. In view of panicle length and grain density, the former seems more crucial in determining grain number per panicle. The present results indicate that it is imperative to break or alleviate the negative relationship between tillering ability and panicle length in order to improve rice yield potential.

Chalkiness, amylose content, and protein content were important parameters related to appearance, cooking and processing, and nutritional qualities of rice [11-12]. The present study found that there was a marked difference in chalky rice rate, amylose content, and protein content both between the two genotypes and among tillers, with the mutant and the later initiated tillers being lower than Xiushui 11 and the earlier initiated tillers, respectively (Table 2). Meanwhile, the mutant and the later tillers had lower grain filling rate than Xiushui 11 and the earlier tillers, respectively (Fig. 2). It may be suggested that tillering capacity affects grain quality mainly due to the changed tiller composition. It was reported that excessive tillers, in particular initiated at later stage could result in increased difference in grain maturity within a plant [2]. Meanwhile, starch synthesis as well as grain quality was affected by climatic factors, especially by temperature at later grain filling stage [13]. Therefore, the more the tillers for a plant, the greater the variation of grain quality within a plant, because the plant with more tillers has more chance of being subjected to different temperatures during grain filling. This may explain for the negative effect of tillering capacity on the uniformity of grain quality within a plant.

There have been many reports about heterogeneity in shoot growth rate, dry matter accumulation, and root development pattern among tillers within a plant [1, 14-16]. However, little has been known about the effect of tillering capacity on the difference in these characters among tillers. In the present study, the mutant had much greater difference in all rice quality parameters among tillers within a plant than Xiushui 11. It is indicated that enhancement of tillering capacity would result in more variable quality within a plant. Accordingly, the uniform quality improvement should be also taken into account in increasing rice yield through enhancing tillering capacity. Moreover, later initiated tillers showed inferior quality than earlier initiated ones. Therefore, it is possible that rice quality will be deteriorated due to excessive tillers within a plant.

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